# Reticle Flatness for Production EUV Lithography

Overlay performance is sensitive to reticle flatness and in-plane distortion. The reticle flatness needed to meet the overlay error budget allocation has negligible impact to the focus and CD control budgets.

Santiago del Puerto

Silicon Valley Group, Lithography Division

901 Ethan Allen Highway
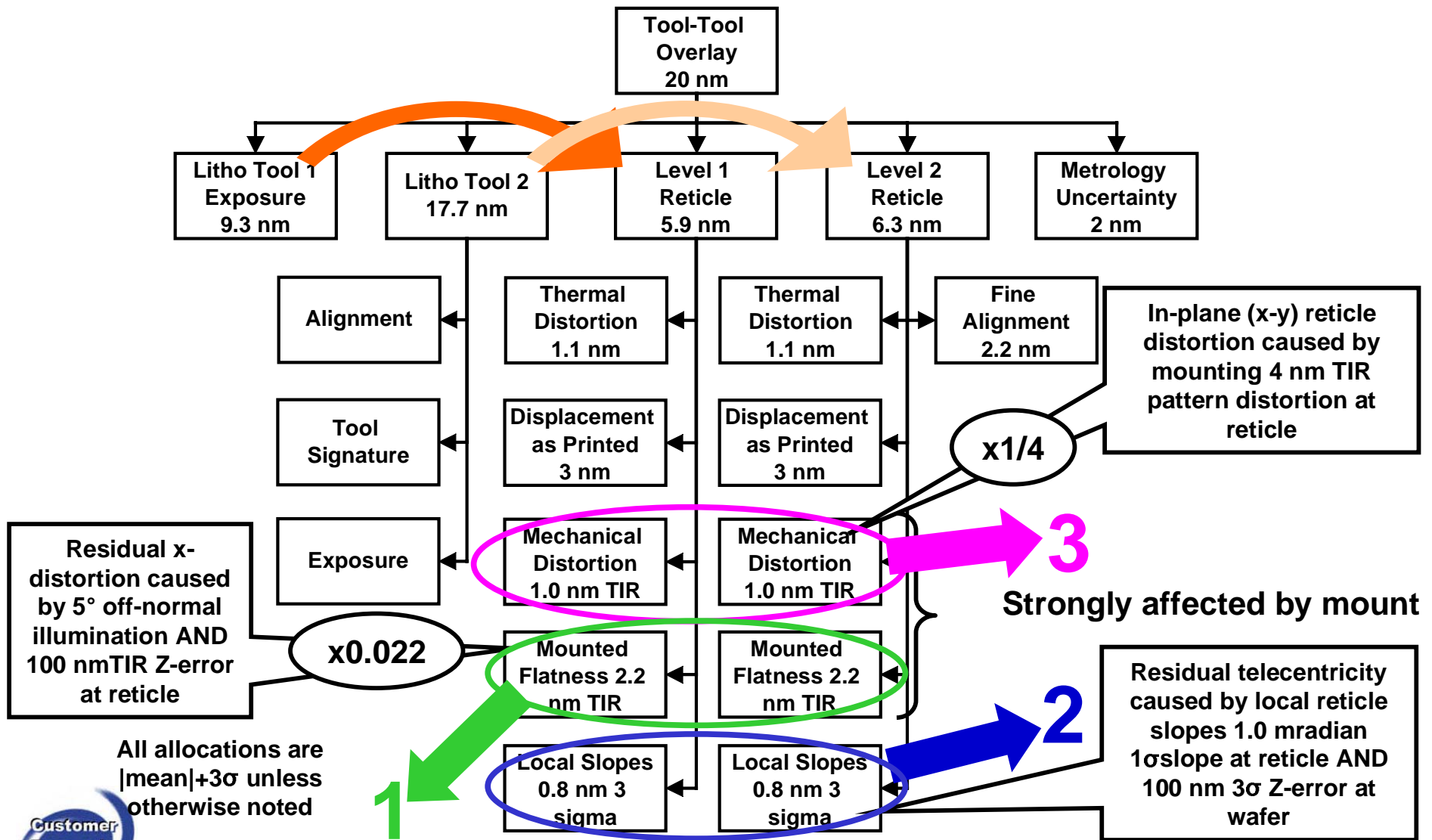
(203) 894-2274

delpuers@svg.com

Dave Hult

Silicon Valley Group, Lithography Division

901 Ethan Allen Highway

(203) 894-2651

hultd@svg.com

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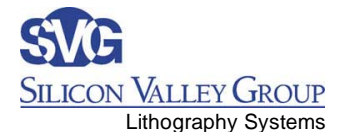
Overlay Error Budget - 50 nm Node

Z-error - z(x,y)

Why ?

All reflective optics

$\downarrow$
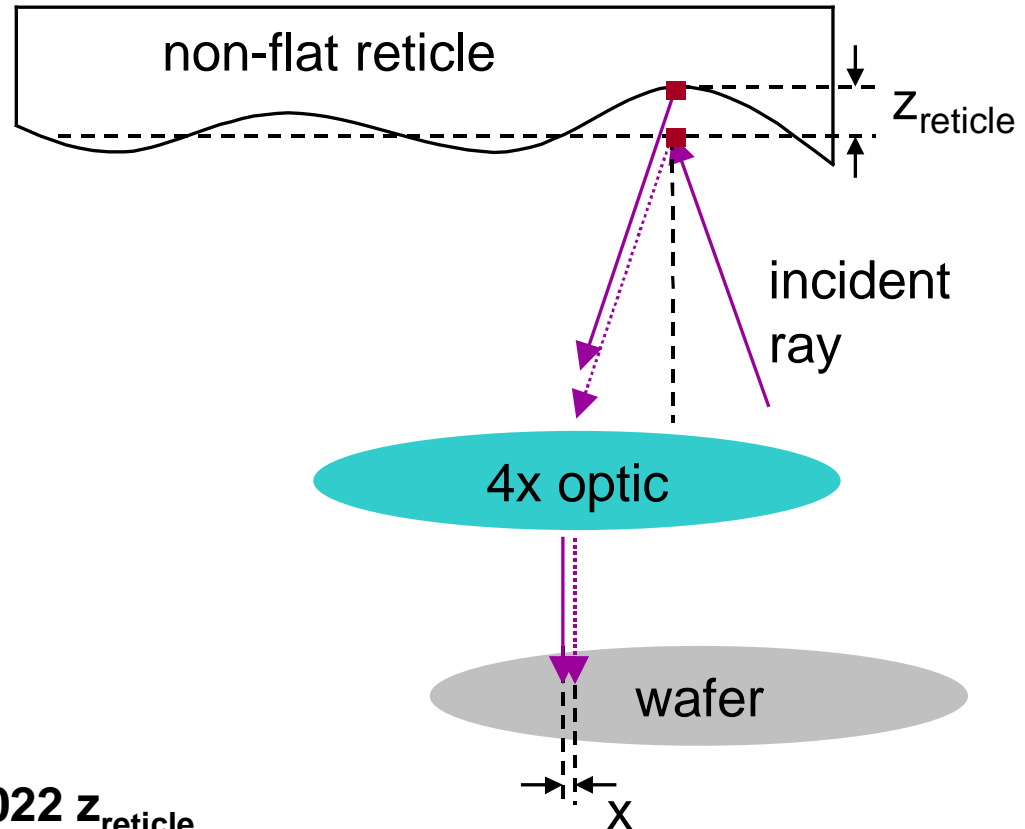
Light must clear mirrors

$\downarrow$

5° incidence angle at reticle

$\downarrow$

Z error at reticle causes X error at wafer

$x_{reticle} = z_{reticle} * \tan 5^o$

$x_{wafer} = z_{reticle} * \tan 5^o/4 = 0.022\, z_{reticle}$

$x_{wafer} = 2.2$ nm TIR   **1**

$z_{reticle} = 100$ nm TIR   **4**

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non-flat reticle

$z_{reticle}$

incident ray

4x optic

wafer

X

Local Slopes - dz/dx (and dz/dy)

Local reticle slope   **Wafer Z-error**

X-Y distortion of projected image
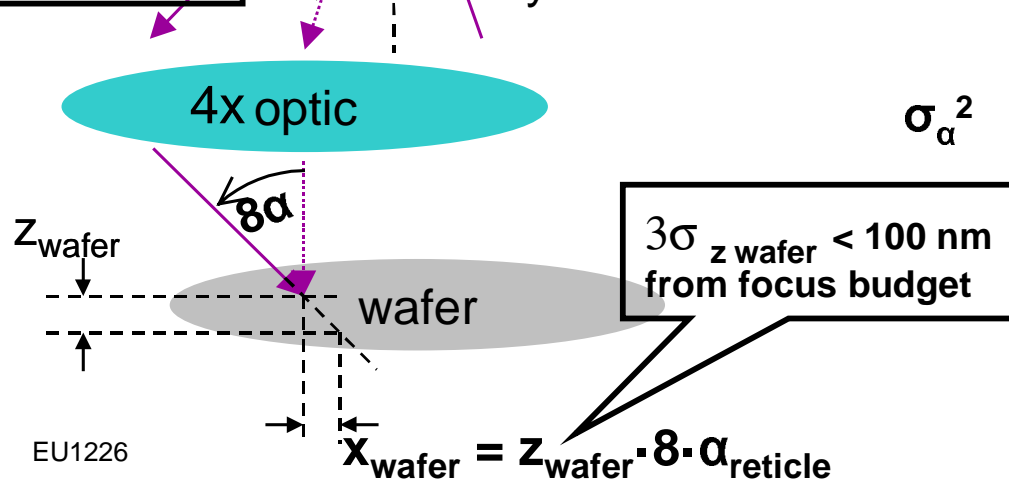
Note: same derivation for x and y

$$3\sigma_x = 3\sigma_z \cdot 8 \cdot \sigma_\alpha < 0.8 \text{ nm}$$
$$3\sigma_z < 100 \text{ nm}$$

2

$$\sigma_\alpha < 1 \text{ mrad}$$

5

non-flat reticle

$\alpha_{reticle}$

$\sigma_{\alpha\ reticle} < 1 \text{ mrad}$
proposed spec.

2α

incident
ray

Local slopes difficult to measure directly
Use power spectral density, $S_{\alpha\alpha}(f)$, to compute variance

4x optic

8α

z_{wafer}

$3\sigma_{z\ wafer} < 100 \text{ nm}$
from focus budget

wafer
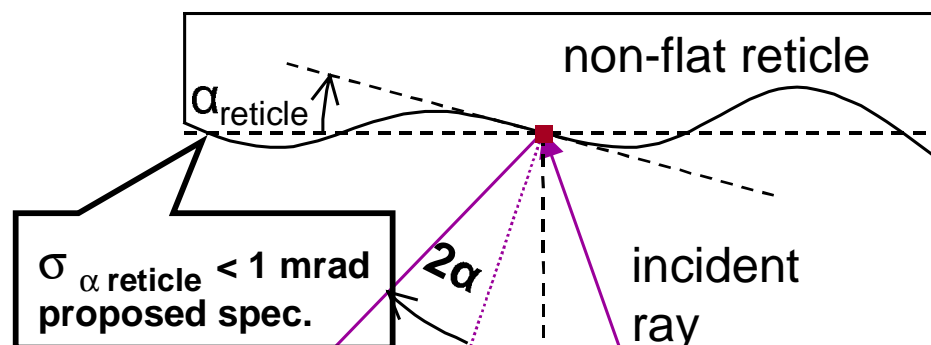
$$\sigma_\alpha^2 = \int_{\frac{1}{100\text{mm}}}^{\frac{1}{400\text{nm}}} S_{\alpha\alpha}(f) df$$

~ feature size

~ reticle field

$$X_{wafer} = z_{wafer} \cdot 8 \cdot \alpha_{reticle}$$

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Spatial Frequency Filtering
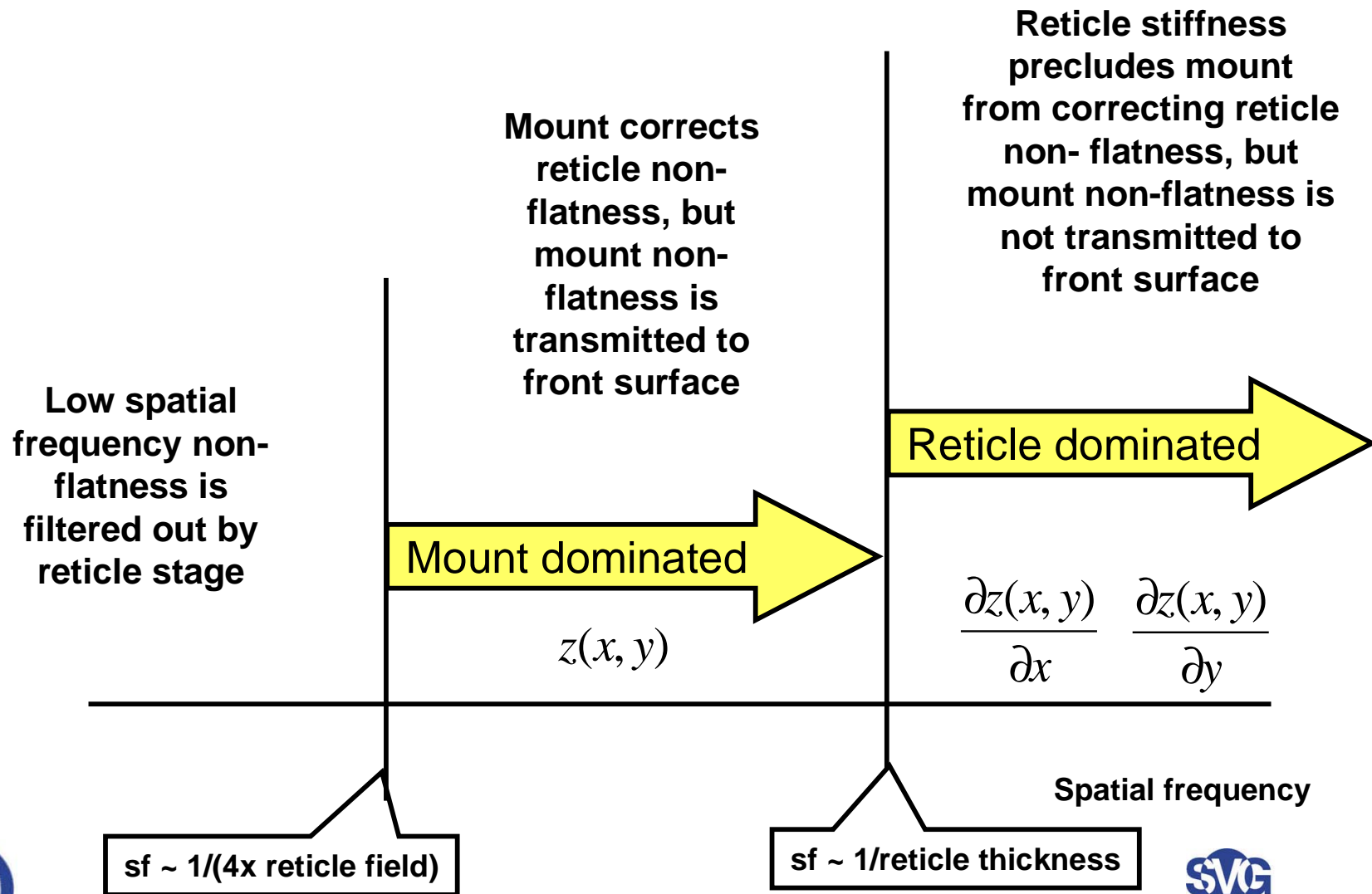
Low spatial frequency non-flatness is filtered out by reticle stage

Mount corrects reticle non-flatness, but mount non-flatness is transmitted to front surface

Reticle stiffness precludes mount from correcting reticle non- flatness, but mount non-flatness is not transmitted to front surface

Mount dominated →

$z(x, y)$

Reticle dominated →

$$\frac{\partial z(x, y)}{\partial x} \quad \frac{\partial z(x, y)}{\partial y}$$

Spatial frequency

sf ~ 1/(4x reticle field)

sf ~ 1/reticle thickness

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Non-flatness sources and filters

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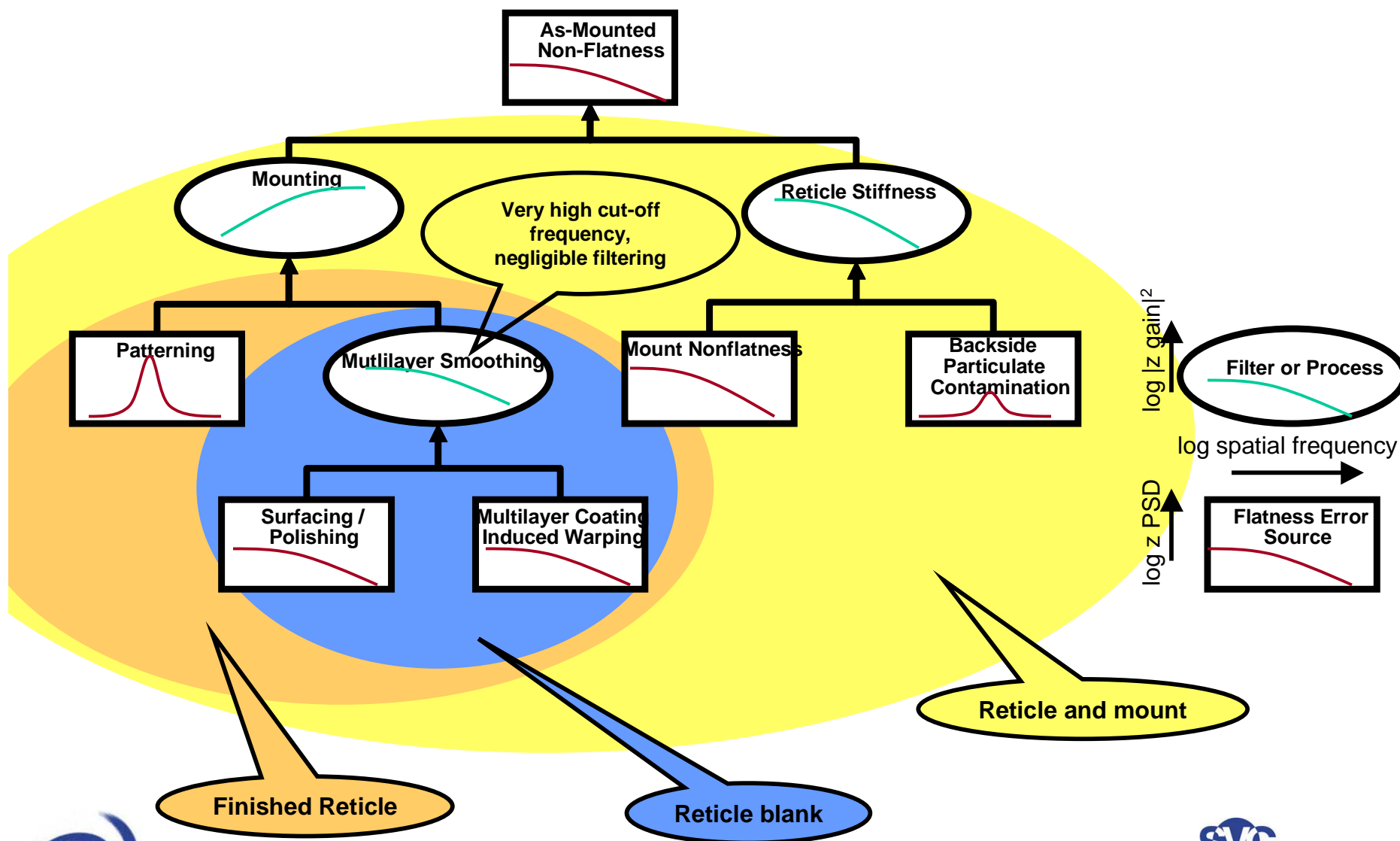
Example Power Spectral Density

z error dominated by low spatial frequency

example PSD specification

rolloff specification

$$\sigma_z{}^2 = \int_{\frac{1}{100mm}}^{\frac{1}{400nm}} S_{zz}(f)df$$

~ reticle field

z PSD (nm^2/mm^{-1})

$$\alpha = \frac{dz(x)}{dx} \qquad S_{\alpha\alpha}(f) = (2 \cdot \pi \cdot f)^2 \cdot S_{zz}(f)$$

slope (α) error dominated by high spatial frequency

$$\sigma_\alpha{}^2 = \int_{\frac{1}{100mm}}^{\frac{1}{400nm}} S_{\alpha\alpha}(f)df$$

~ feature size x 4

α PSD (mrad^2/mm^{-1})

spatial frequency (mm^{-1})

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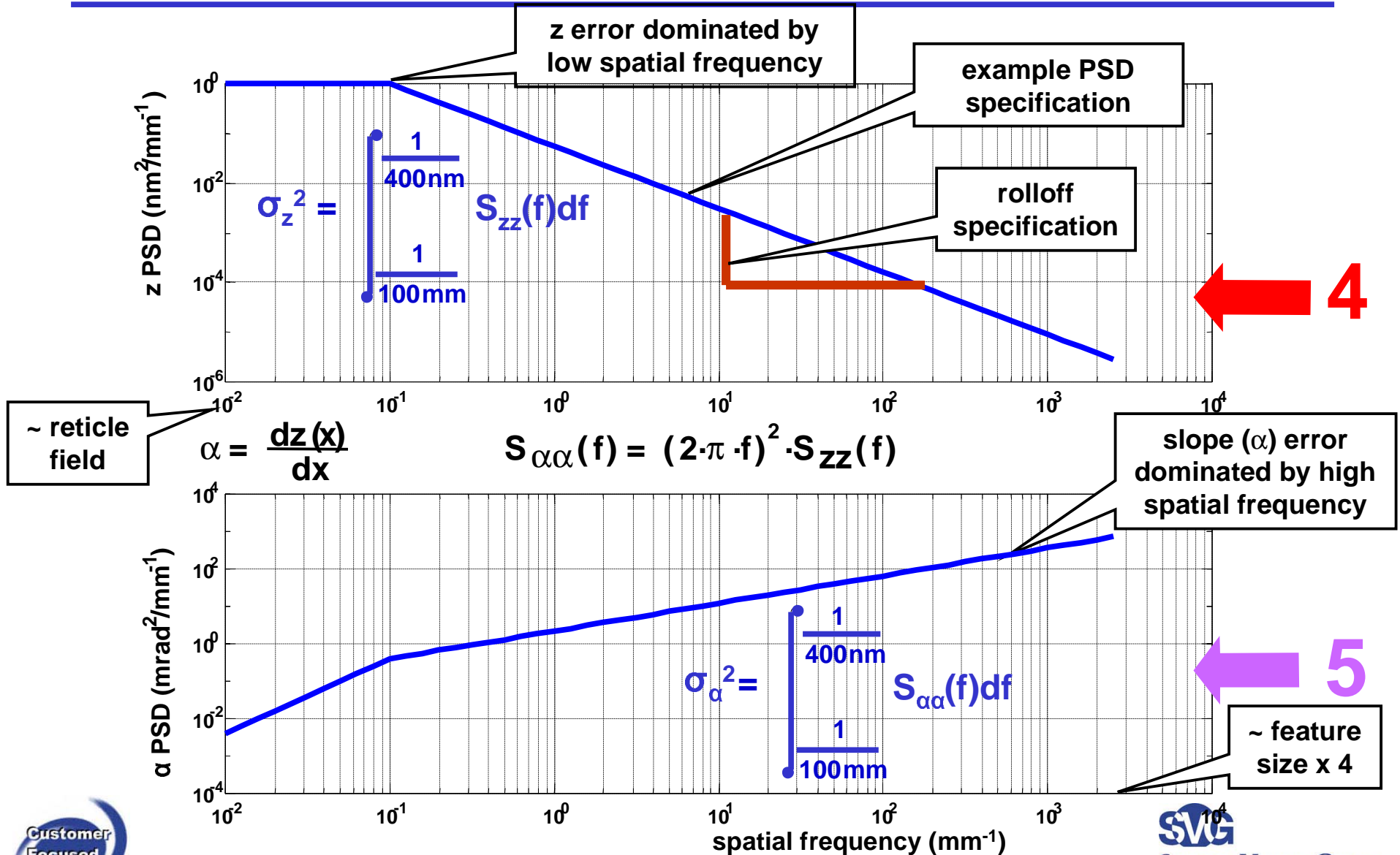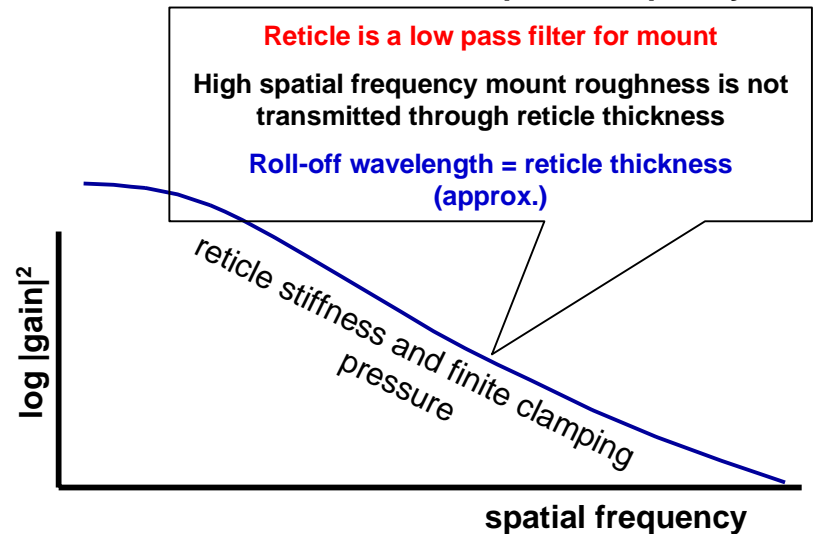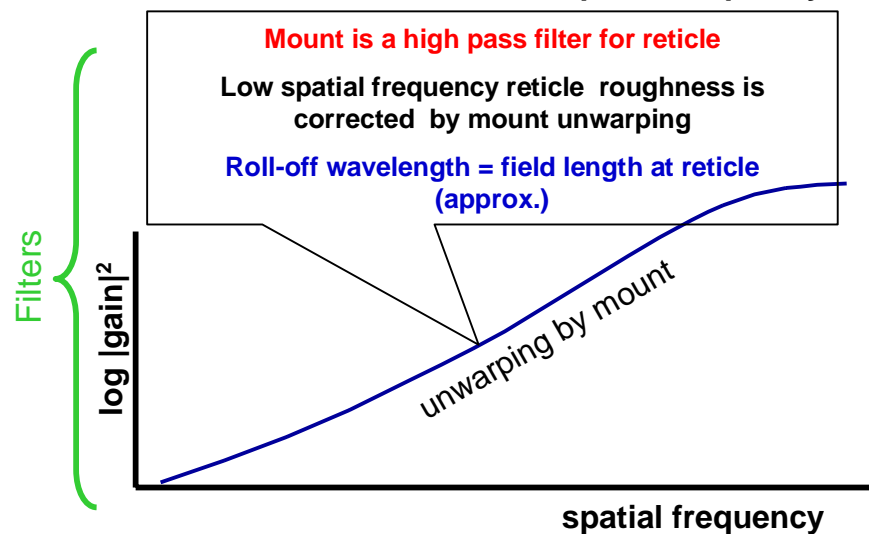
Proposed "As mounted" Simulation
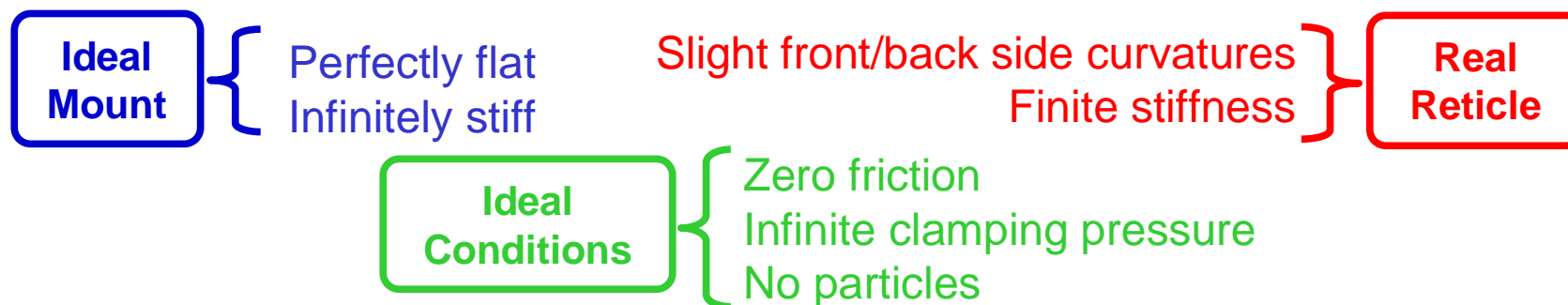
Filtering of reticle non-flatness by mount
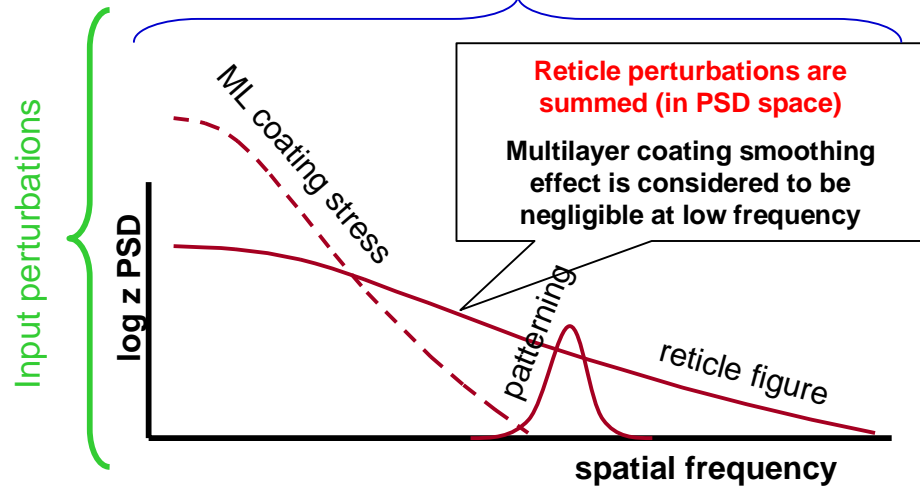
Filtering of mount non-flatness by reticle

Input perturbations

ML coating stress

log z PSD

Reticle perturbations are summed (in PSD space)

Multilayer coating smoothing effect is considered to be negligible at low frequency

patterning

reticle figure

spatial frequency

mount non-flatness

log z PSD

Mount perturbations are summed (in PSD space)

contamination

spatial frequency

Filters

Mount is a high pass filter for reticle

Low spatial frequency reticle roughness is corrected by mount unwarping

Roll-off wavelength = field length at reticle (approx.)

log |gain|²

unwarping by mount

spatial frequency

Reticle is a low pass filter for mount

High spatial frequency mount roughness is not transmitted through reticle thickness

Roll-off wavelength = reticle thickness (approx.)

log |gain|²

reticle stiffness and finite clamping pressure
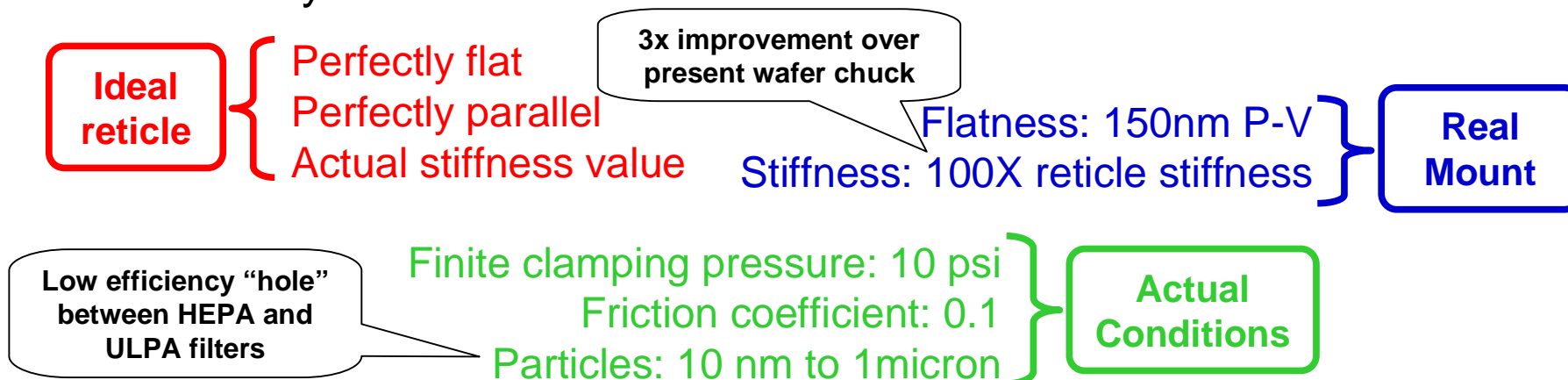
spatial frequency

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Proposed Detailed Analysis

- **What can we expect from a real reticle on a real mount?**

 - A. Analysis of a real reticle on ideal mount under ideal conditions

  Ideal Mount { Perfectly flat / Infinitely stiff

  Slight front/back side curvatures / Finite stiffness } **Real Reticle**

  Ideal Conditions { Zero friction / Infinite clamping pressure / No particles

  - B. Analysis of a "flat" reticle on real mount under actual conditions

  Ideal reticle { Perfectly flat / Perfectly parallel / Actual stiffness value

  3x improvement over present wafer chuck

  Flatness: 150nm P-V / Stiffness: 100X reticle stiffness } **Real Mount**

  Low efficiency "hole" between HEPA and ULPA filters

  Finite clamping pressure: 10 psi / Friction coefficient: 0.1 / Particles: 10 nm to 1micron } **Actual Conditions**

  - C. Combine results from A and B

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Ideal Reticle/Real Mount Study

- Transmission of mount non-flatness through reticle
  - Quantify spectral frequency cut-off of the reticle stiffness low-pass filter and its variation with clamping pressure

- Investigate magnitude of secondary effects
  - What happens when there is relative motion between the reticle and the mount under load?

Sliding contact points
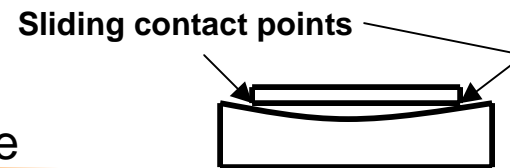
- Slightly concave chuck surface

3

- **Reticle pattern compression AND**
- **Sliding of reticle/chuck contact points during loading**
  - » **Chuck / reticle wear**
  - » **Particulate generation**

This may need experimental verification

Slightly convex chuck surface

3

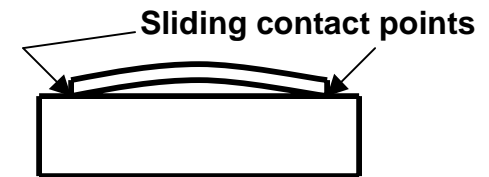- **Reticle pattern expansion only, no sliding contact points?**

Some adverse mounting effects may depend on mount curvature (slightly concave or slightly convex)

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Real Reticle/Ideal Mount Study

- Flattening of reticle non-flatness by mount
  - Quantify spectral frequency cut-off of the mount high-pass filter and its variation with clamping pressure

- Investigate magnitude of secondary effects
  - What happens when there is relative motion between the reticle and the mount under load?

Sliding contact points

- Slightly concave reticle backside surface
  - **Reticle pattern compression AND**
  - **Sliding reticle/chuck contact points during loading**
    - » **Chuck / reticle wear**
    - » **Particulate generation**

This may need experimental verification

- Slightly convex reticle backside surface
  - **Reticle pattern expansion only, no sliding contact points**

Some adverse mounting effects may depend on reticle curvature (slightly concave or slightly convex)

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Reticle Flatness Standards Approach

- **Agree on "As-mounted" reticle flatness requirement**
  - Specified across spatial frequency domain
- **Co-operate to derive consistent set of lower level standards**
  - Finished reticle flatness across spatial frequency domain
  - Mount flatness across spatial frequency domain
  - Minimum clamping pressure
  - High spatial frequency mask distortion transmission vs. clamping pressure
- **Review specifications in progress to insure consistency**
  - Reticle blank standard
- **Apply standards set uniformly across all critical processes to partially cancel mounting distortion contributions to overlay error**
  - Mask writing
  - Mask inspection
  - Lithographic exposure

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